NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3827

EXPERIMENTAL INVESTIGATION OF A LIGHTWEIGHT ROCKET CHAMBER

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SUMMARY

Experiments have been conducted with a jacketed rocket combustion chamber that was fabricated by hydraulic forming from sheet metal. Rocket combustion chambers made by this method have been used successfully. Runs with these combustion chambers have been made at over-all heat-transfer rates of 2.5 Btu per square inch per second with water cooling and also with ammonia as a regenerative coolant.

INTRODUCTION

For rocket operation beyond a few seconds duration, provisions must be made for cooling the combustion chamber surfaces. Usually this is accomplished by circulating a coolant between the combustion chamber wall and a coolant jacket wall. The high heat-transfer rates across the chamber surfaces dictate chamber walls of limited thickness and a coolant passage designed to provide a high velocity of coolant through the jacket. This entails rather critical dimensional tolerances both for the chamber wall and the coolant jacket. For flight propulsion application, it is desirable that the engine weight be kept to a minimum and that one of the propellants be used as a coolant (regenerative cooling).

Rocket combustion chambers for experimental work usually have been fabricated by contour machining either from solid metal or from tubular stock spun to a shape. The machining involved requires expensive specialized equipment and consumes many man-hours of highly skilled labor. Further, there are practical limitations to the wall thicknesses that can be machined.

The NACA Lewis laboratory has experimented with jacketed rocket combustion chambers fabricated by hydraulic forming from sheet metal. This fabrication method not only provides chambers with thin walls for combustion research and cooling research, but also affords relatively lightweight chamber structure.

[1]Supersedes recently declassified NACA Research Memorandum E52L19a by John E. Dalgleish and Adelbert O. Tischler, 1953.

The purpose of this report is to discuss some test results for the lightweight rocket combustion chambers formed from sheet metal. The fabrication technique is given in the appendix.

DESCRIPTION OF ENGINE

The type of jacketed rocket combustion chamber which is discussed in this report is illustrated in figure 1. The engine illustrated has a nominal thrust rating of 1000 pounds at a chamber pressure of 300 pounds per square inch. Thrust chambers of 1000- and 5000-pound thrust with operating chamber pressures of 600 pounds per square inch have been made by the same technique. The coolant jacket comprises an inner and outer sheet-metal skin. The outer skin is shaped to form three or four helically wound coolant passages. In the engine illustrated these coolant passages lead directly into the rocket injection head, thus providing for regenerative cooling of the chamber.

For engines operated at a chamber pressure of 600 pounds per square inch with regenerative cooling (jacket pressures of the order of 800 lb/sq in.), it was necessary to reinforce the outer shell to prevent ballooning. Such reinforcement was accomplished by wrapping the chamber with several layers of fiberglass cloth, bonded with a polyester resin glue. The external valleys between adjacent cooling passages were first filled with a low-strength filler material.

The engine illustrated in figure 1 weighed 3.5 pounds. This is a ratio of thrust to weight of 285; therefore, this chamber assembly compares favorably in thrust-to-weight ratio with flight engines of considerably larger size.

For research purposes where engine weight is not a primary consideration, the chamber assembly is welded to a flange to permit attaching an injector and to facilitate mounting on the thrust stand.

EXPERIMENTAL TESTS

Thrust chambers fabricated by the hydraulic-forming method have been used in a number of experimental programs. Propellants used include liquid oxygen and ammonia, liquid oxygen with hydrocarbons, and high-impulse propellant combinations. For liquid oxygen with either ammonia or hydrocarbons as fuel, regenerative cooling as well as water cooling has been used. Run durations ranged to 60 seconds.

Sample data for runs made in this type of engine with various types of injectors are given in the following table. The characteristic length was usually between 30 and 40 inches. In all cases, nozzles designed for expansion to atmospheric pressures were used.

Propellant	Thrust, lb	Chamber pressure, lb/sq in. abs	Oxidant-fuel ratio	Specific impulse, (lb)(sec)/lb	Over-all heat transfer, Btu/(sq in.)(sec)
Oxygen-ammonia (water cooled)	980	280	1.3	208	1.5
	1030	285	1.7	216	1.7
Oxygen-ammonia (regeneratively cooled)	830	255	1.1	---	0.9
	955	---	1.4	208	1.3
Oxygen-hydrocarbon (water cooled)	1100	615	2.8	254	2.5
	1080	625	2.3	260	2.0
	1050	612	2.1	254	1.7
	5240	620	3.2	254	1.4
	5490	650	2.6	258	1.2
	5740	680	2.1	260	1.0

DISCUSSION

These engines were proved to be rugged and durable in the tests performed at this laboratory. Over-all heat-transfer rates above 5 Btu per square inch per second were measured with high-impulse propellants in a 1000-pound-thrust engine without failures. Occasional burnouts were experienced. Some of these burnouts occurred at the throat of the engine. Such burnouts could generally be attributed to the injector design; that is, similar burnouts were experienced with substitute chambers equipped with the troublesome injector. Heat-transfer rates with such injectors have usually been very high.

For the fabrication of more than one rocket combustion chamber, the technique outlined in this report has resulted in savings in time and cost over the contour machining methods that the method replaced. The total time for one chamber is about equal to that required for an equivalent machined rocket chamber. However, an additional chamber can be made with a completed die in about 10 percent of the time required for the first chamber. Thus, it is clear that when several chambers are made, the cost per chamber is greatly reduced. Material costs are also lessened. The procedure produces very little scrap metal. Exclusive of the material in the mandrel and die, about 60 percent of the starting metal ends up in the final chamber assembly.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, December 1, 1952

APPENDIX - METHOD OF FABRICATION

The procedure for fabricating combustion chambers from sheet metal consists in forming two close-fitting coaxial metal shells over a mandrel and expanding the outer shell into a female die shaped to form the cooling passages. The outer shell expansion is accomplished by the application of hydraulic pressure.

Chamber Walls

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The steps required to make the inner and outer combustion chamber walls are illustrated in figure 2 and are as follows:

The initial step is the manufacture of a two-piece mandrel, machined of steel in two parts so that it may be separated at the nozzle throat (fig. 2(a)). The mandrel is machined to the required inside diameter of the rocket combustor chamber, heat treated, and surface finished.

The inner shell, which eventually comprises the rocket combustion-chamber wall, is made of sheet metal to the approximate shape of the chamber by rolling up cones corresponding to the converging and diverging parts of the nozzle and a cylinder corresponding to the cylindrical section of the chamber (fig. 2(b)). These rolled patterns are welded together over the mandrel by the heliarc welding technique. The welded structure is then cold-formed to the shape of the mandrel on an engine lathe by use of a spinning roll (fig. 2(c)).

The outer shell, which eventually forms the coolant jacket, is similarly made of sheet-metal patterns (fig. 2(d)). These patterns are rolled and welded together over the mandrel plus the first shell, which is not removed from the mandrel. The second shell is then cold spun to fit against the first shell. The two shells are welded together along the ends (fig. 2(e)). After the plaster model is made as outlined in the next section, two small tubes are sealed to the outer shell (fig. 2(f)). These tubes are for the purpose of applying hydraulic pressure between the shells; one tube serves as an air bleed. The assembly is at no time removed from the mandrel.

Die

The coolant passage die is made around the mandrel plus its two shells. This procedure assures accurate fitting between the die and the rocket body shape. The die need be made only for the first chamber; thereafter any number of chambers may be formed in the same die. The steps in making the die are diagrammed in figure 3 and are as follows:

The desired final shape of the outer chamber wall is simulated by wrapping beeswax moldings of half-circular cross sections to the outer shell of the rocket motor (fig. 3(a)). Tapered wax moldings are used where it is required to make a coolant passage of reduced section, as in the venturi section of the rocket nozzle. Thick sections are molded at the beginning and end of the chamber to form the inlet and exit coolant manifolds. Parting lines along the length of the chamber are made on the wax form by cutting slots in the wax moldings and inserting metal shims in these slots on opposite sides of the form. A bismuth-tin alloy of low melting temperature is then sprayed onto the wax and outer shell to make a female mold of the final shape of the outer shell. This mold is removed from the outer shell at the parting lines and the wax stripped from the convolutions in the mold. The two halves of the mold are placed together, with the metal shims inserted, and plaster is poured into the mold to form a male plaster model of the final outer shell shape. The low-melting-temperature metal is then melted off the plaster cast. The cast is placed into an oven and dried. The plaster cast is placed into a lathe and a shell of steel is sprayed onto it by the high-temperature metallizing process.

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The sprayed steel female form is centered in a thick-walled metal cylinder made of two flanged halves which can be bolted together. The two halves of the cylinder are separated by shims. An alloy metal is poured into the space between the sprayed steel form and the thick-walled cylinder to back and strengthen the steel (fig. 3(b)).

The shims between the two halves of the thick-walled cylinder are removed and the steel form is sawed apart between the flanges of the cylinder and through the center of the sprayed steel form. The plaster is removed from the two halves and new shims are made. To replace the metal removed in sawing, the new shims are cut to fit the contours of the two halves of the die (fig. 3(c)). Passages for the pressurizing tubes are cut in the die. This completes the rocket body die.

Hydraulic Forming

The mandrel with the inner and outer shells is now placed into the die (fig. 4(a)) and hydraulic pressure of 5000 pounds per square inch is applied between the inner and outer shells through the tubes. The pressure expands the outer shell to form the coolant passages and, upon removal of the die (fig. 4(b)), the rocket chamber assembly is essentially complete. It is only necessary to remove the pressurizing tubes and to weld on tubes to conduct the coolant to and away from the rocket motor. A 1000-pound-thrust rocket combustion chamber is shown being removed from the die in figure 5.

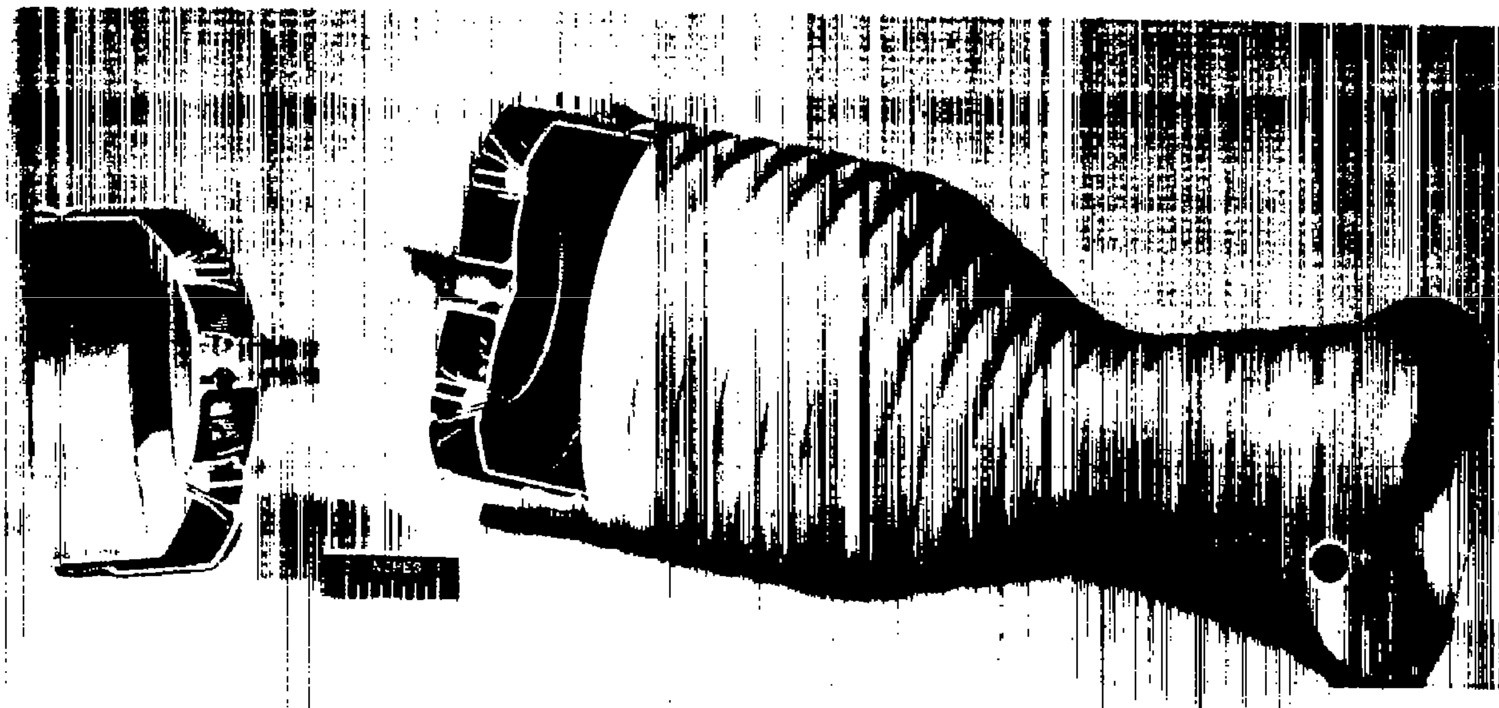

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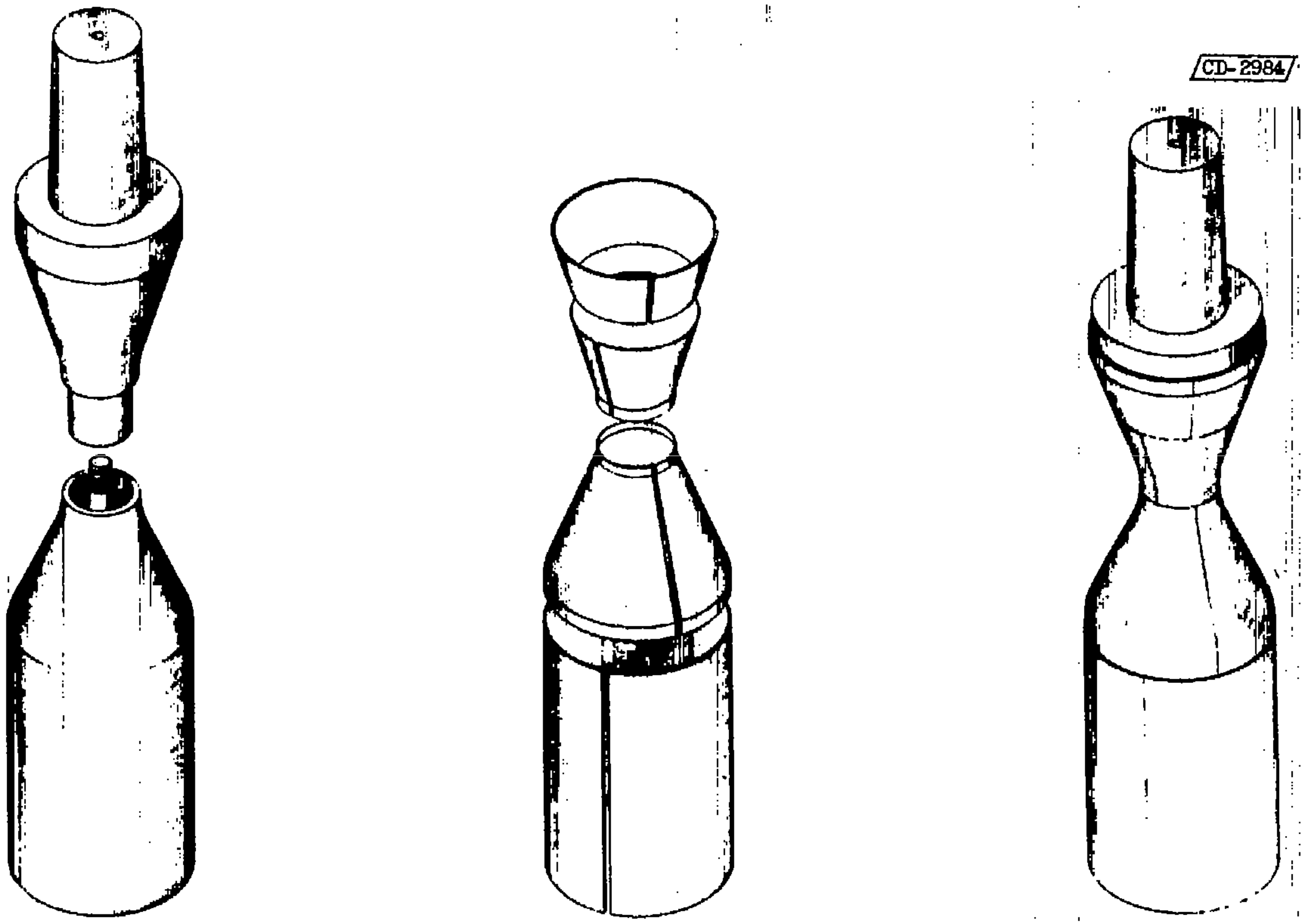
Figure 1. - 1000-pound-thrust chamber equipped with injector to use regenerative coolant.

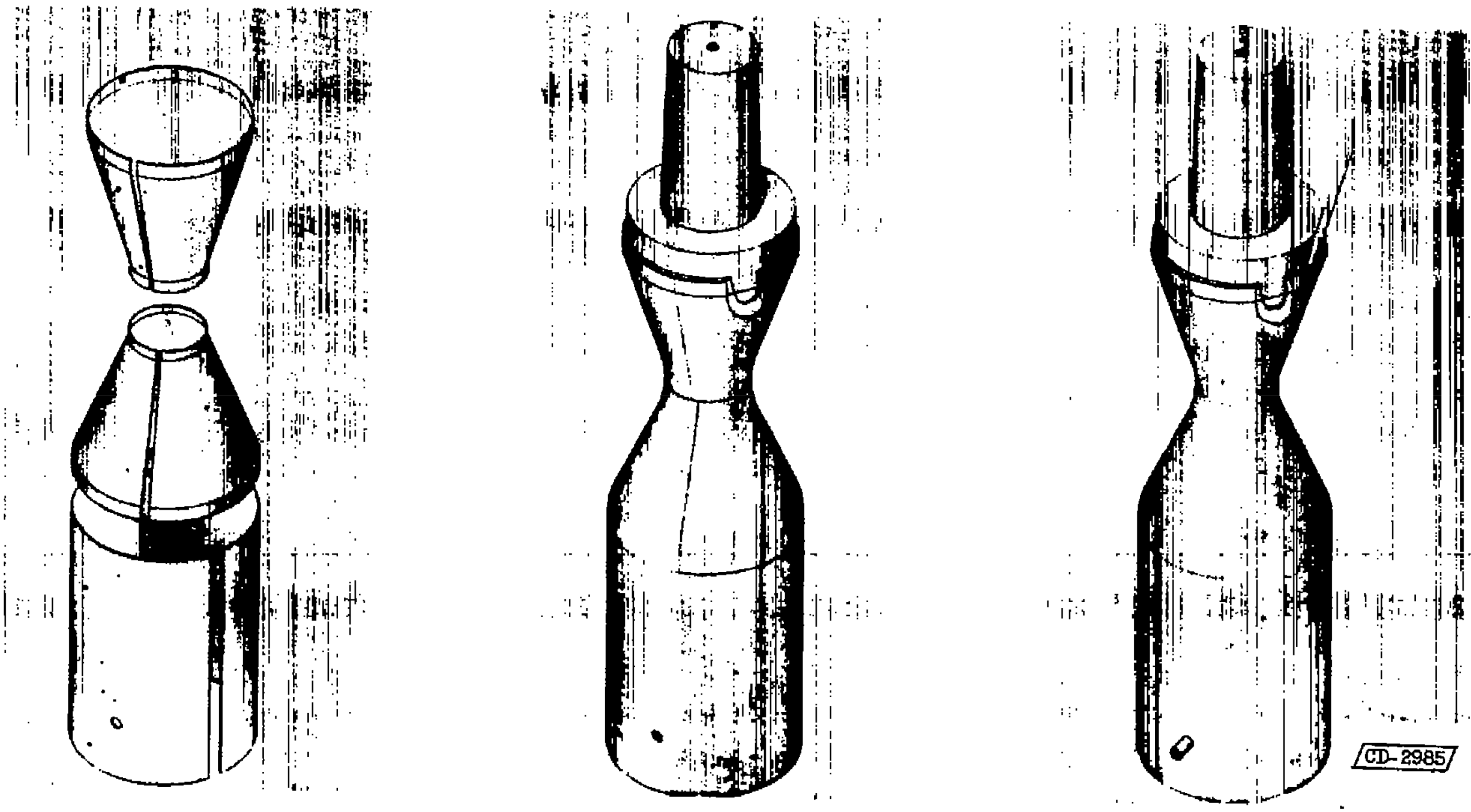


(a) Two-piece solid steel mandrel.

(b) Inner sheet-metal shell components.

(c) Inner shell components heliarc-welded together and cold-formed to mandrel.

Figure 2. - Initial steps in fabrication of chamber walls for lightweight rocket chamber.

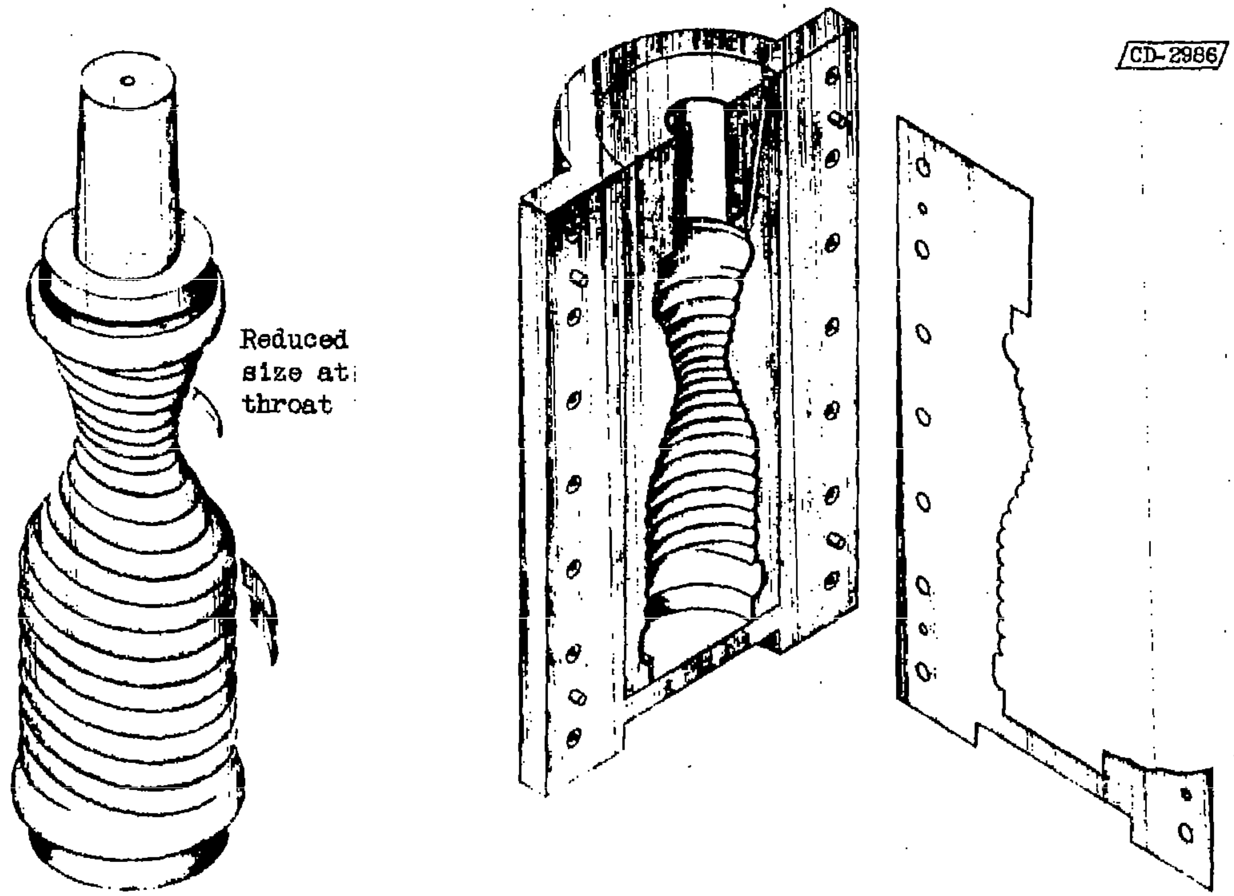


(d) Outer shell components.

(e) Outer shell components welded together and cold-formed metal-to-metal on inner shell and mandrel. Inner and outer shells welded together along upper and lower edges.

(f) Tubes, 1/4 inch, welded to shells for hydrostatic pressurizing after preparation of transfer mold. Transfer mold necessary only for preparation of die.

Figure 2. - Concluded. Initial steps in fabrication of chamber walls for lightweight rocket chamber.

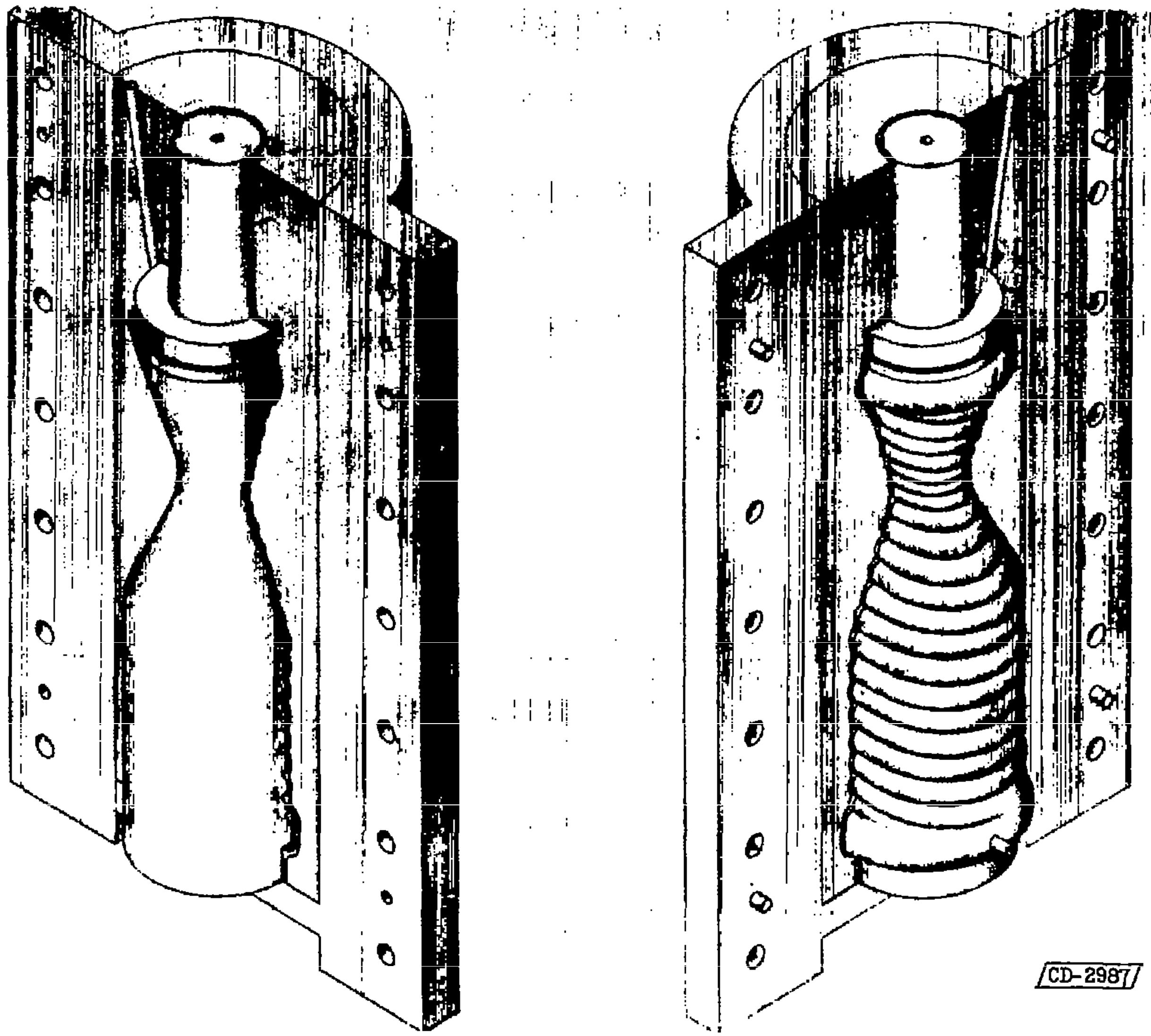


(a) Solid beeswax cooling passage molds applied over shells on mandrel. Female mold made in low-melting alloy from this body. Male plaster master cast in female mold. Male plaster cast covered with steel shell applied with metalizing gun.

(b) Metal-coated plaster cast is placed inside heavy wall steel jacket and surrounding volume filled with alloy metal. Jacket and contents are sawed in half on the center line forming a split die.

(c) Metal lost in saw cut replaced by shim.

Figure 3. - Preparation of die



(a) Mandrel with inner and outer shells placed in die. (b) Rocket body after hydraulic pressure of 5000 pounds per square inch has been applied between inner and outer shells.

Figure 4. - Hydraulic forming of coolant passages.

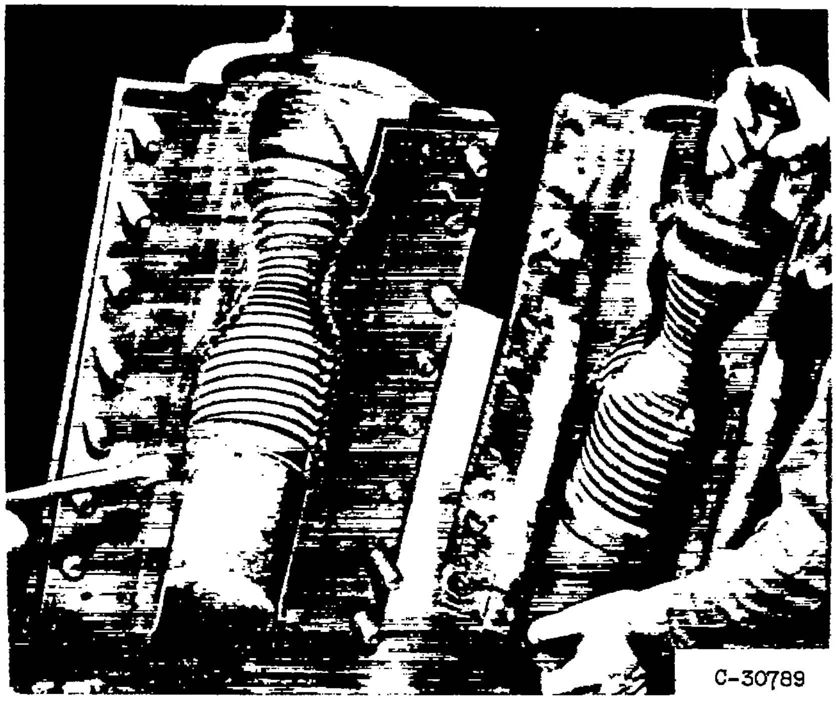


Figure 5. - Removal of 1000-pound-thrust chamber from die.